Agenda for Today

Today-
- Revision
- Project report and presentation formats
- Submit Assignment-4

Next classes:
- May 6: Final
- May 8: Presentation
After Mid-Term Exam (1)

- Modeling motion of a single vehicle
  - Case of constant speed
  - Case of constant acceleration
  - Case of varying acceleration
  - Equations of motion as a functions of speed and distance
  - Vehicle trajectories
Modeling motion of group of interacting vehicles (Car Following Theory)
- Pipe’s theory
- Forbe’s theory
- General Motor’s five models
- Gipps Model
- Car Following Theory Application
- Tracking two vehicle problem
- Plotting the data and analyzing results
Fundamentals of pre-timed signal timing design
- Development of signal timing phase plans
- Procedural steps for signal timing design
- Important terms: cycle length, phase, interval, all red, yellow, green, saturation flow, peak hour factor, critical lane volume, lost time
- Pedestrian requirements
- Lag lead signal timings
After Mid-Term Exam (4)

- Fundamentals of actuated signal timing design
  - Actuation types
  - Detector types and detection technologies
  - Operation of actuated signals
  - Actuated signal timing and design
After Mid-Term Exam (5)

- **Traffic flow fundamentals using detectors**
  - Single detector system
  - Two detector system
  - Microscopic characteristics
  - Macroscopic characteristics
After Mid-Term Exam (6)

- Highway capacity software
- Paramics
- Synchro
- Visit to Region-4 TMC
• **Shock Wave Analysis**
  - Shock wave speed
  - Forward and backward shockwave
  - Application in recurring congestion
  - Application during incidents
  - Number of vehicles affected because of shock wave
  - Queue length
  - Time to clear the queue
Delay

- The most common measure used to describe operational quality at a signalized intersection is delay.
- Delay refers to the amount of time consumed in travelling the intersection
  - The difference between the arrival time and departure time
Forms of Delay

- **Stopped time delay**
  - Defined as the time of a vehicle is stopped in queue while waiting to pass through the intersection
  - Average stop time delay is the average of all vehicles during a specified time period

- **Approach delay**
  - Included stopped delay
  - but adds the time loss due to deceleration from the approach speed to a stop and the time loss due to reacceleration back to desired speed
• **Time-in-queue delay**
  ○ Defined as the total time from a vehicle joining an intersection queue to its discharge across the STOP line on departure

• **Travel time delay**
  ○ More of a conceptual value
  ○ Difference between driver’s expected travel time through the intersection and the actual time taken.
  ○ Difficult to obtain “desired” value, so this is a philosophical concept

• **Control delay**
  ○ Delay caused by the control device (either a traffic signal or stop sign)
  ○ Approximately = time-in-queue delay + acceleration-deceleration delay
Delay Measures

Average delay is measured as sec/vehicle

- D1 = stopped-time delay
- D2 = approach delay
- D3 = travel time delay
Basic Theoretical Models of Delay

- Cumulative Vehicles
- Slope = \( v \)
- \( Q(t) \)
- Slope = \( s \)
- Aggregate Delay
  (veh-secs)
- Time (secs)
- G R G
- Time \( t \)
- Veh \( i \)
- \( W(i) \)
Delay Components

- Assuming no pre-existing queue vehicles arriving when the light is green continue through the intersection
- When the light turns RED, vehicles arrive but do not depart
- Thus departure curve is parallel to the x-axis during RED interval
Delay Components (1)

- When the next effective GREEN begins, vehicles queued during RED intervals depart from the intersection
- Departure curve “catches up” with the arrival curve before the next RED interval begins
Delay Components (2)

- The total time that any vehicle “i” spends waiting in the queue, $W(i)$, is given by the horizontal time-scale difference between the time of arrival and the time of departure.
- The total number of vehicles queued at any time $t$, $Q(t)$, is the vertical scale difference between the number of vehicles that have arrived and the number of vehicles that have departed.
Delay Components (3)

- The average delay for all vehicles passing through the signal is the area between the arrival and departure curve (vehicles x time)
Delay Scenario (1)

(a) Stable Flow

Cumulative Vehicles, $i$

arrival function, $a(t)$

departure function, $d(t)$

Time, $t$
Delay Scenario (2)

Cumulative Vehicles, $i$

arrival function, $a(t)$

departure function, $d(t)$

(b) Individual Cycle Failures Within a Stable Operation
Delay Scenario (3)

(c) Demand Exceeds Capacity for a Significant Period
Arrival Patterns

Uniform Arrivals
(a)

Random Arrivals
(b)

Reality = Platoon Arrivals—No Theoretical Solution Available
(c)
Components of Delay

- **Uniform Delay**
  - Delay based on an assumption of uniform arrivals and stable flow with no individual cycle failures

- **Random Delay**
  - Additional delay above and beyond uniform delay because flow is randomly distributed rather than uniform at isolated intersection

- **Overflow Delay**
  - Additional delay that occurs when the capacity of an individual phase or series of phases is less than the demand or arrival flow rate
Webster’s Uniform Delay

Cumulative Vehicles

Slope = \( v \)

\( R = C \left[ 1 - \frac{g}{C} \right] \)

\( t_c \)

Aggregate Delay (veh-secs)

Time (secs)

G R G
Uniform Delay

\[ UD_a = 0.5RV \]
- Aggregate uniform delay, veh-sec
- length of red phase, sec
- total vehicles in queue, veh

Where,

\[ R = C \left[ 1 - \left( \frac{g}{C} \right) \right] \]

C -> cycle length, sec
g-> effective green time, sec
Derivation of Uniform Delay
Random Delay

- The uniform delay model assumes that arrivals are uniform and that no signal phases fail, i.e.
- Arrival flow is less than capacity during every signal cycle of the analysis period
- At isolated intersections, vehicle arrivals are more likely to be random
- A number of stochastic models have derived
- Such models assume that inter-vehicle arrival times are distributed according to Poisson distribution with underlying average arrival rate of $v$ vehicles per unit time
Random Delay

- Such models account for both the underlying randomness of arrivals and the fact that some individual cycles could fail because of randomness.
- The additional delay is referred as “overflow delay”, but it does not address $v/c > 1.0$.
- The most frequently used random delay as per Webster’s formulation as below:

$$RD = \frac{X^2}{2v(1 - X)}$$

RD- $\rightarrow$ Average random delay per vehicle, sec/veh
X- $\rightarrow$ $v/c$ ratio
The formulation found to somewhat overestimate delay, and Webster proposed total delay as following:

\[ D = 0.9(UD + RD), \text{ where } D \rightarrow \text{Sum of uniform and random delay} \]
Overflow Delay

- Oversaturation is used to describe extended time periods during which arriving vehicles exceed capacity of the intersection approach to discharge vehicles.
- In such cases queues grow and overflow delay, in addition to uniform delay accrues.
- Because overflow delay accounts for the failure of an extended series of phases, it encompasses a portion of random delay as well.
Delay in Oversaturated Period

Cumulative Vehicles
- Overflow Delay
- Uniform Delay

Slope = \( s \)
Slope = \( c \)
Slope = \( v \)
Uniform Delay when X=1

- Uniform delay when v/c = 1.0 is referred as UD₀

\[
UD₀ = \frac{0.5C[1 - (\frac{g}{c})]^2}{1 - (\frac{g}{c})X}
\]

When X=1
\[
UD₀ = 0.5C[1 - (\frac{g}{c})]
\]
Overflow Delay for a Time Period

\[ OD_a = \frac{1}{2} T(vT - cT) = \frac{1}{2} T^2 (v - c) \]
\[ OD = \frac{T}{2} [X - 1] \]

Where,

\( OD_a \rightarrow \) Aggregate overflow delay, veh-sec
\( OD \rightarrow \) Average overflow delay per vehicle, sec/veh
Overflow Delay Between Two Time Periods

\[ \text{Overflow Delay} (OD) = \frac{T_1 + T_2}{2} (X - 1) \]
The inconsistency occurs when $v/c$ is in the vicinity of 1.0.
Inconsistencies in Random and Overflow Delay (2)

- If the v/c ratio is below 1.0, then a random delay model is being used
  - Because there is no overflow delay in this case

\[
RD = \frac{X^2}{2v(1 - X)}
\]

RD-> Average random delay per vehicle, sec/veh
X-> v/c ratio

- As X approaches 1.0, random delay increases asymptotically
Inconsistencies in Random and Overflow Delay (3)

- When v/c ratio is greater than 1.0, then overflow delay model is applied

\[
OD_a = \frac{1}{2} T (vT - cT) = \frac{1}{2} T^2 (v - c)
\]

\[
OD = \frac{T}{2} [X - 1]
\]

Where,

- \(OD_a\) -> Aggregate overflow delay, veh-sec
- \(OD\) -> Average overflow delay per vehicle, sec/veh

- However, when \(X=1\), \(OD=0\)
- But increases uniformly with increasing values of X thereafter
Inconsistencies in Random and Overflow Delay (4)

- Neither model is accurate in the vicinity of $X=1$
- In terms of practical terms, most studies confirms that the uniform delay is a sufficient predictive tool (except the issue with platooned arrivals) when the $v/c$ ratio is 0.85 or less.
- In this range the true value of random delay is miniscule and there is no overflow delay.
Similarly, the simple theoretical overflow delay is a reasonable predictor when $v/c \geq 1.15$

The problem is that the most interesting case fall in the intermediate range
- $0.85 < v < 1.15$

For which neither model is adequate

Much of the recent work in delay modeling attempts to bridge this gap
Commonly used Formula

\[ OD = \frac{cT}{4} \left[ (X - 1) + \sqrt{(X - 1)^2 + \left( \frac{12(X - X_0)}{cT} \right)} \right] \]

Where,

\[ X_0 = 0.67 + \left( \frac{sg}{600} \right) \]

T-> Analysis period, hrs
X-> v/c ratio
C-> Capacity, veh/hr
s-> Saturation flow rate, veh/sec/green
g-> Effective green time, sec
Example-1

- An intersection approach has an flow rate of 1000 veh/hr, a saturation flow rate of 2,800 veh/hr/gr, a cycle length of 90 sec, and g/C ratio of 0.55. What average delay per vehicle is expected under these condition?